Fast Micro-mirrors with Large Angle Deflections

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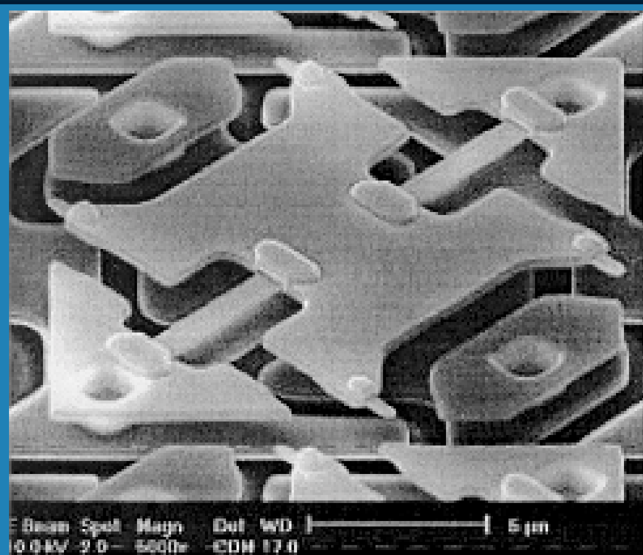
Liquid MEMS

- Liquids don’t suffer from stiction.
- Liquids don’t suffer from wear and fatigue.
- Electrostatic actuation.
- Thermal actuation.
- Patterned fluid dispensing of 14 pL drops that are 30µm in diameter with ~1µm accuracy.

TI Digital Micromirror



- Constraints on opposite sides of mirror
- Residual stress deflects mirror, useless as analog mirror
- Mechanical weak links are thermal insulators
- Rotates only about one axis

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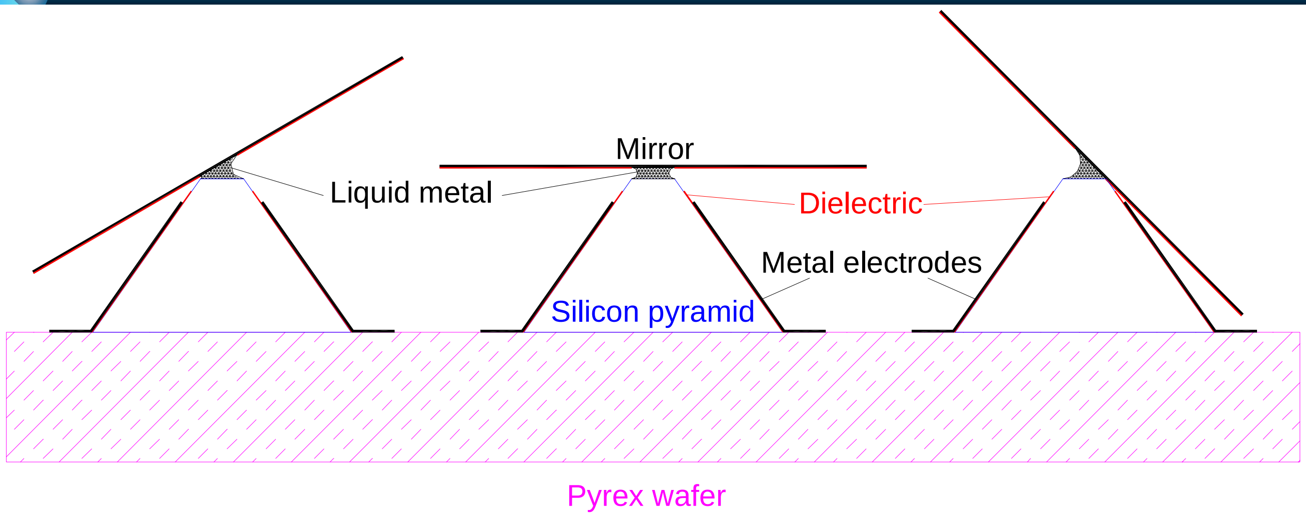
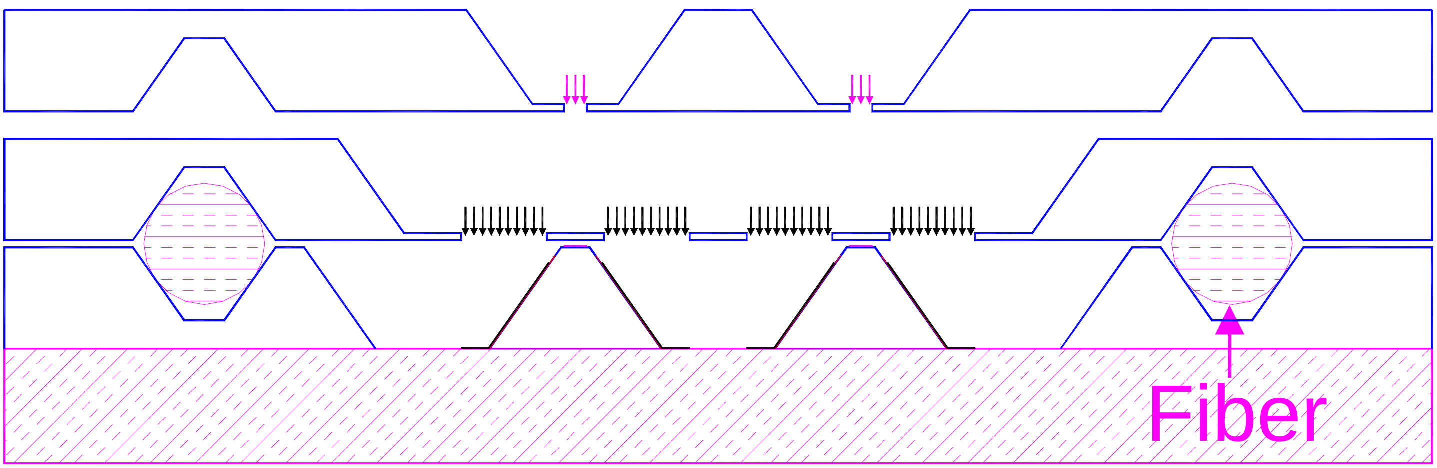
UIC Micro-mirror



Conducting liquid drop gives.

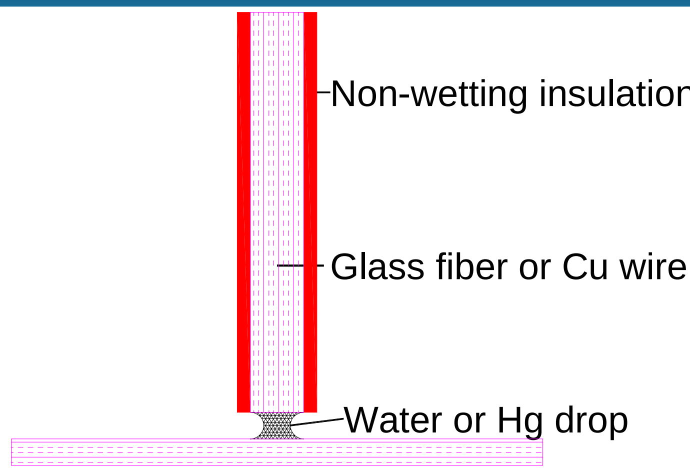
- Restoring force.
- Electrical connection to moveable plate for electrostatic actuation.
- Good thermal connection to moveable plate.

Lithography on Non-planar Substrates



Aligned shadow masks can selectively deposit or etch thin films on non-planar substrates.

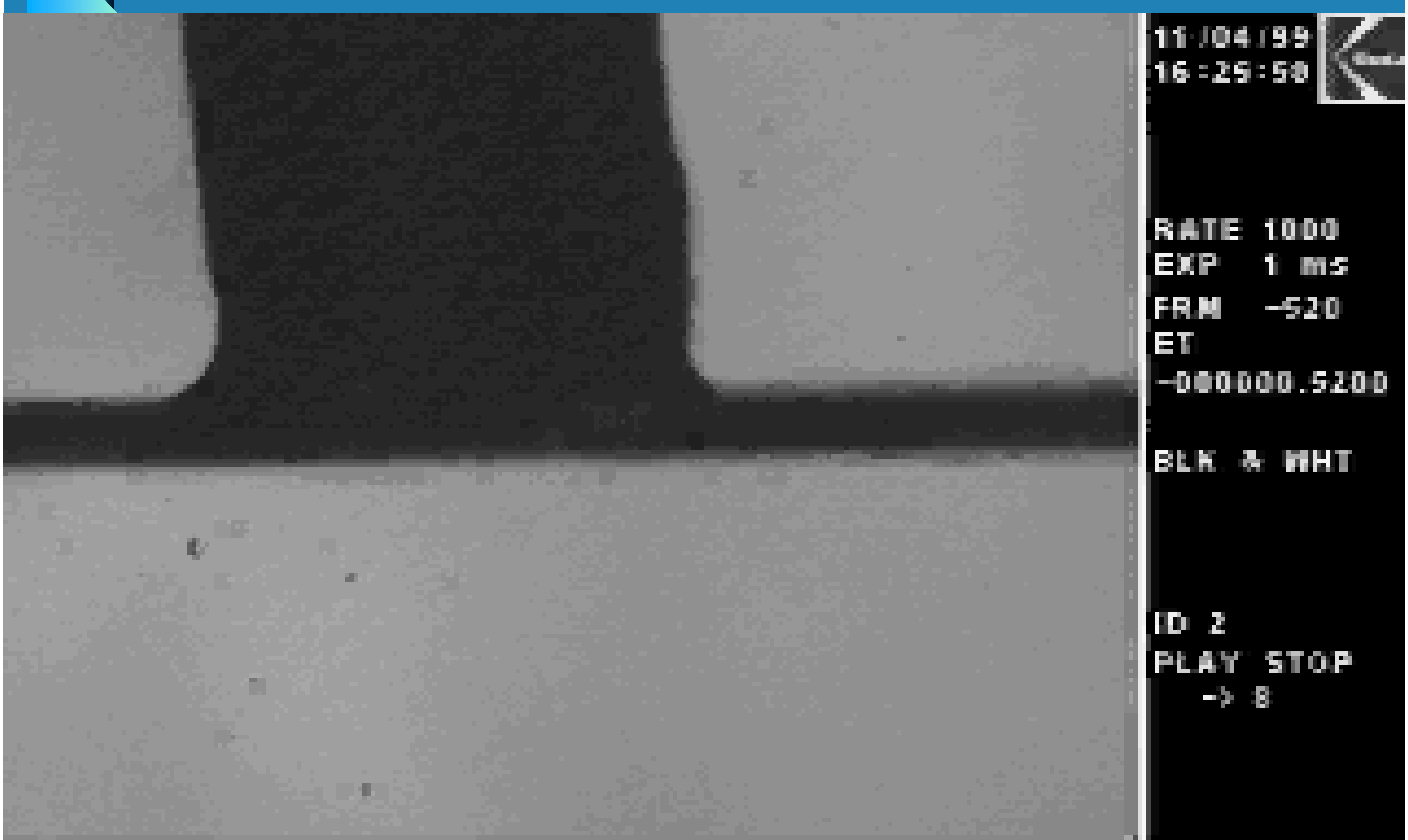
Prototype Micromirror



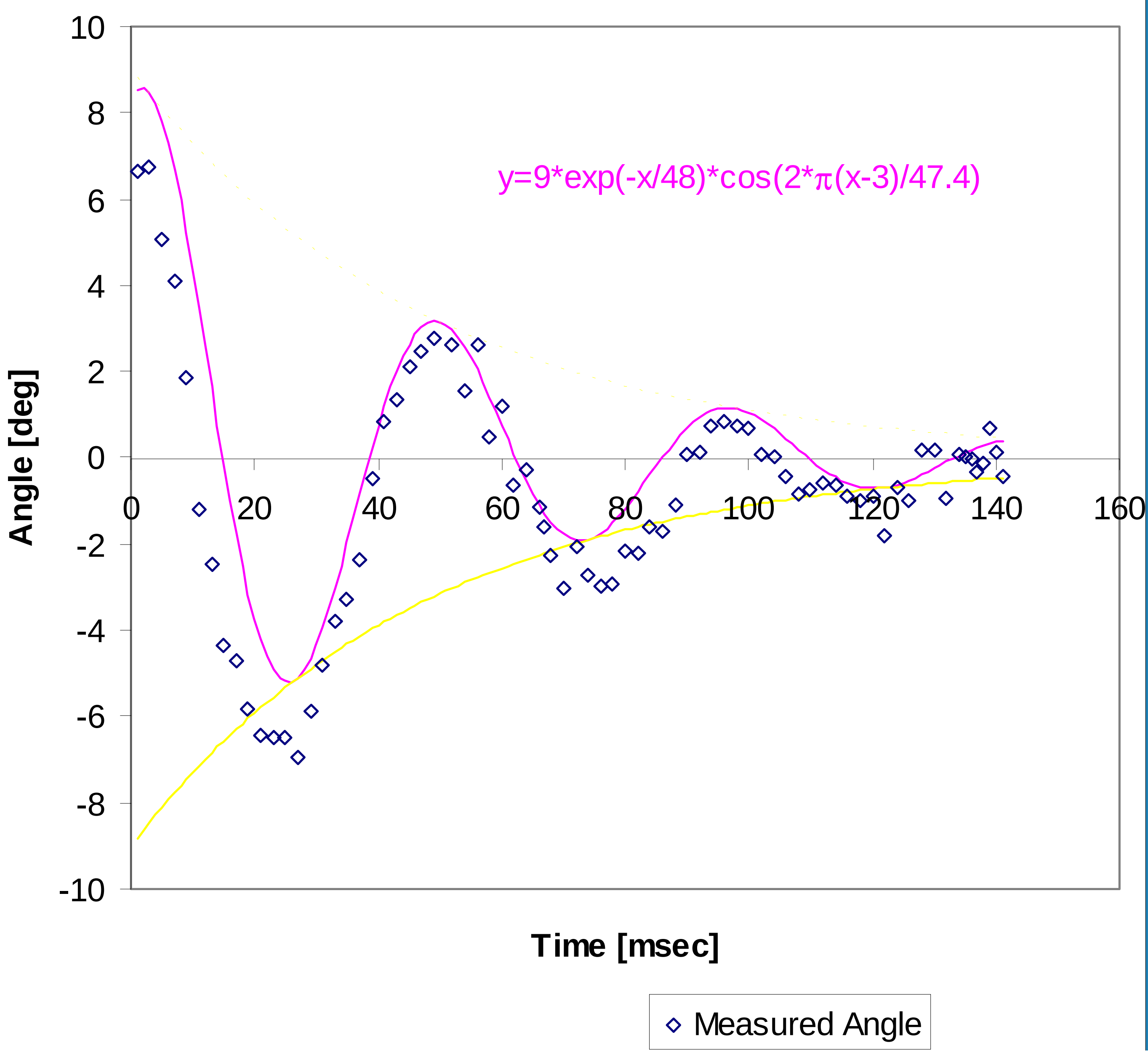
~1mm glass fiber + wax

Glass slide ~5x2x.15mm^3

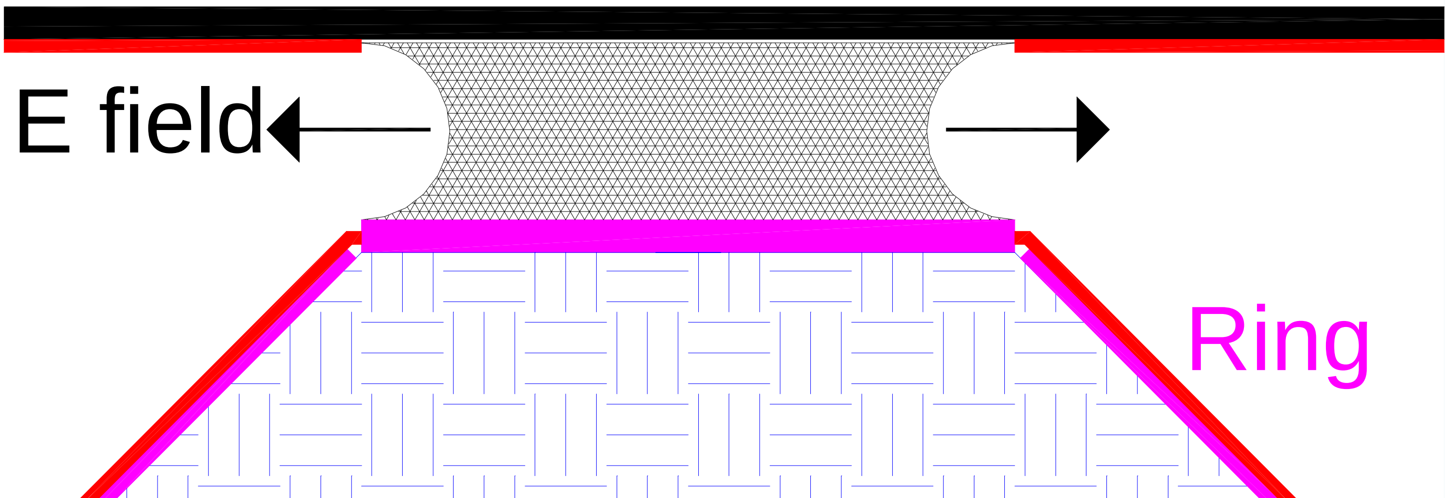
DI Water


11/04/99
16:25:58
RATE 1000
EXP 1 ms
FRM -520
ET
-000000.5200
BLK & WHT
ID 2
PLAY STOP
-> 8

Deflection Angle vs. Time

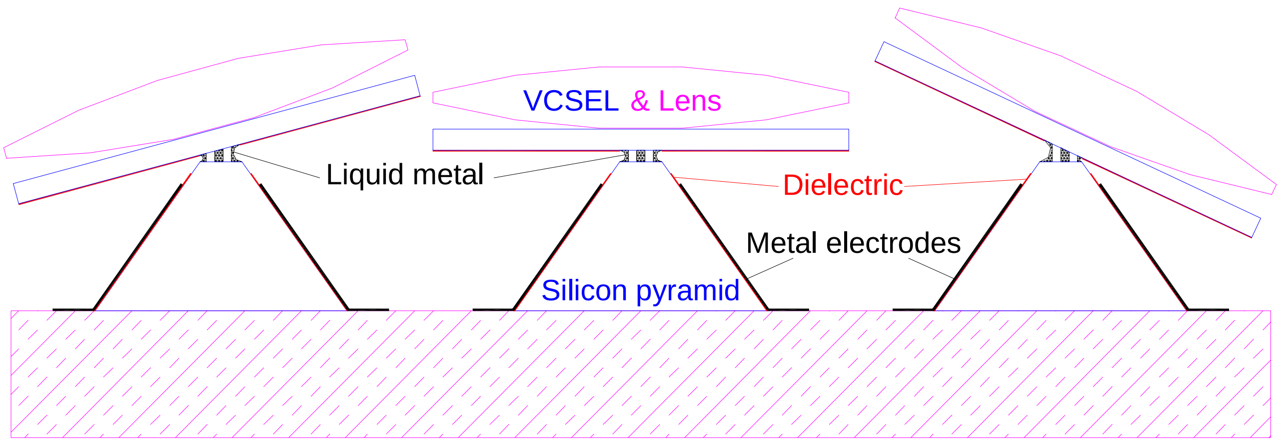


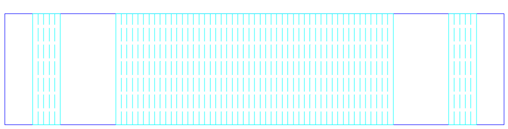
Piston Motion



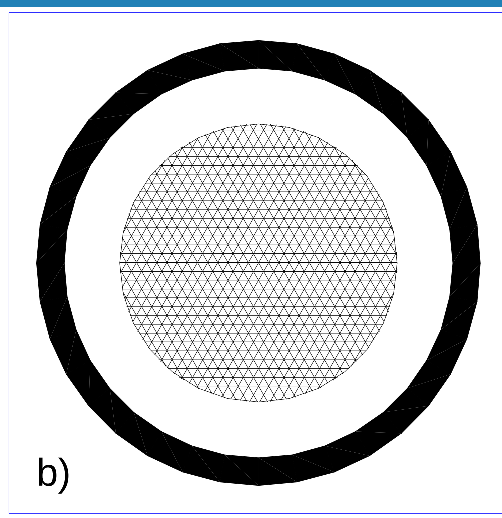
A potential applied between liquid and ring electrode will cause the liquid to creep out from under the mirror.

Electrostatically Actuated VCSEL





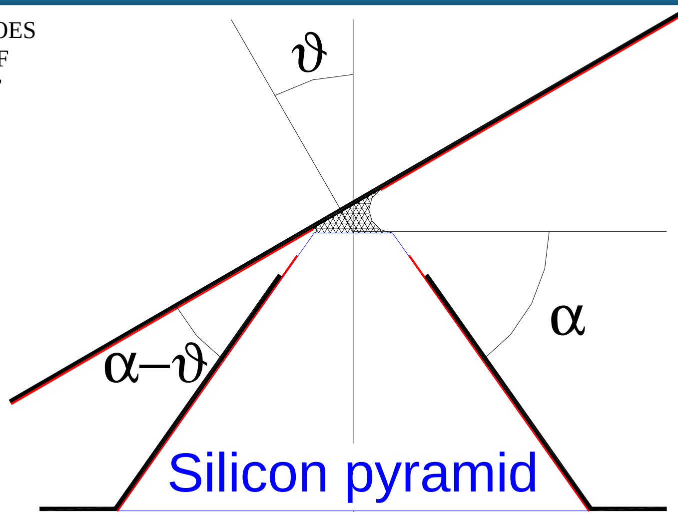
a)



b)

Concentric liquid metal drop provides electrical power to moveable plate.

Torque vs. Angle from Surface Tension

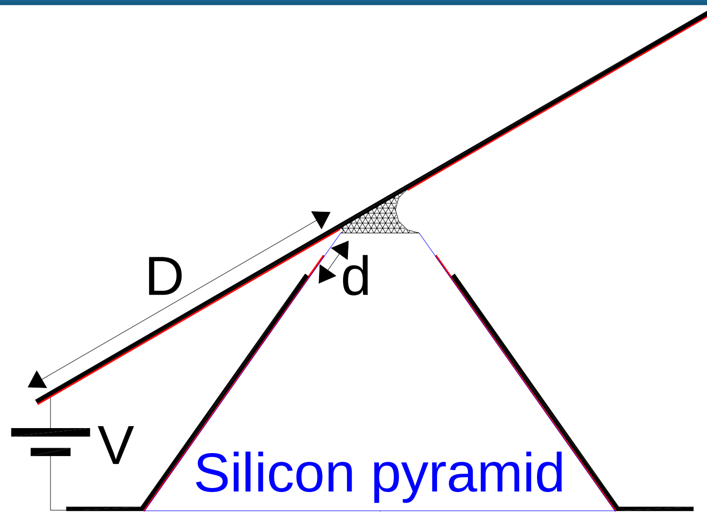


$$S(\theta) = 2L + (\pi - \theta)R_L(\theta) + (\pi + \theta)R_S(\theta)$$

$$S(\theta) \cong S(0) + C2 * \left(\frac{\theta}{2}\right)^2 + C4 * \left(\frac{\theta}{2}\right)^4$$

$$\Gamma_l(\theta) = -\gamma \frac{dS(\theta)}{d\theta} \approx -\frac{\gamma * C2 * \theta}{2}$$

Electrostatic Torque vs. Angle



$$E_\theta(r) = \frac{V}{r(\alpha-\theta)} \qquad \sigma(r) = \frac{\varepsilon_0 V}{r(\alpha-\theta)}$$

$$Q = \frac{\varepsilon_0 V}{\alpha-\theta}\ln\left(\frac{D}{d}\right) \qquad C(\theta) = \frac{\varepsilon_0}{\alpha-\theta}\ln\left(\frac{D}{d}\right)$$

$$U(\theta) = -\frac{C(\theta)V^2}{2} = -\frac{\varepsilon_0 V^2}{2(\alpha-\theta)}\ln\left(\frac{D}{d}\right)$$

Low Spring Constant for x-Area

- Liquid mercury, γ~0.51N/m
- Drop ~37μm·37μm ·10μm
- Spring constant k~0.5γC2 ~1.1nNm

- Aluminum bar ~ 1μm·2μm ·10μm
- Spring constant ~1.2nNm

Dynamics

$$I\frac{d^2\theta}{dt^2}+\lambda\frac{d\theta}{dt}=k\theta$$

$$\omega=\sqrt{\frac{k}{I}}=\sqrt{\frac{\gamma 90\times 10^{-6}}{mD^2}}$$

Formula predicts 250ms period, movie ~40ms

Dynamics

Reduce mirror size from $0.15 \cdot 2 \cdot 5\,mm^3$ and 3.5mg to $0.02 \cdot 0.2 \cdot 0.2\,mm^3$ and 7μg, period less than 1ms

Evaporation Rate

$$G := P\_drop \cdot \left(\frac{M}{2 \cdot \pi \cdot R \cdot T\_drop} \right)^{.5}$$

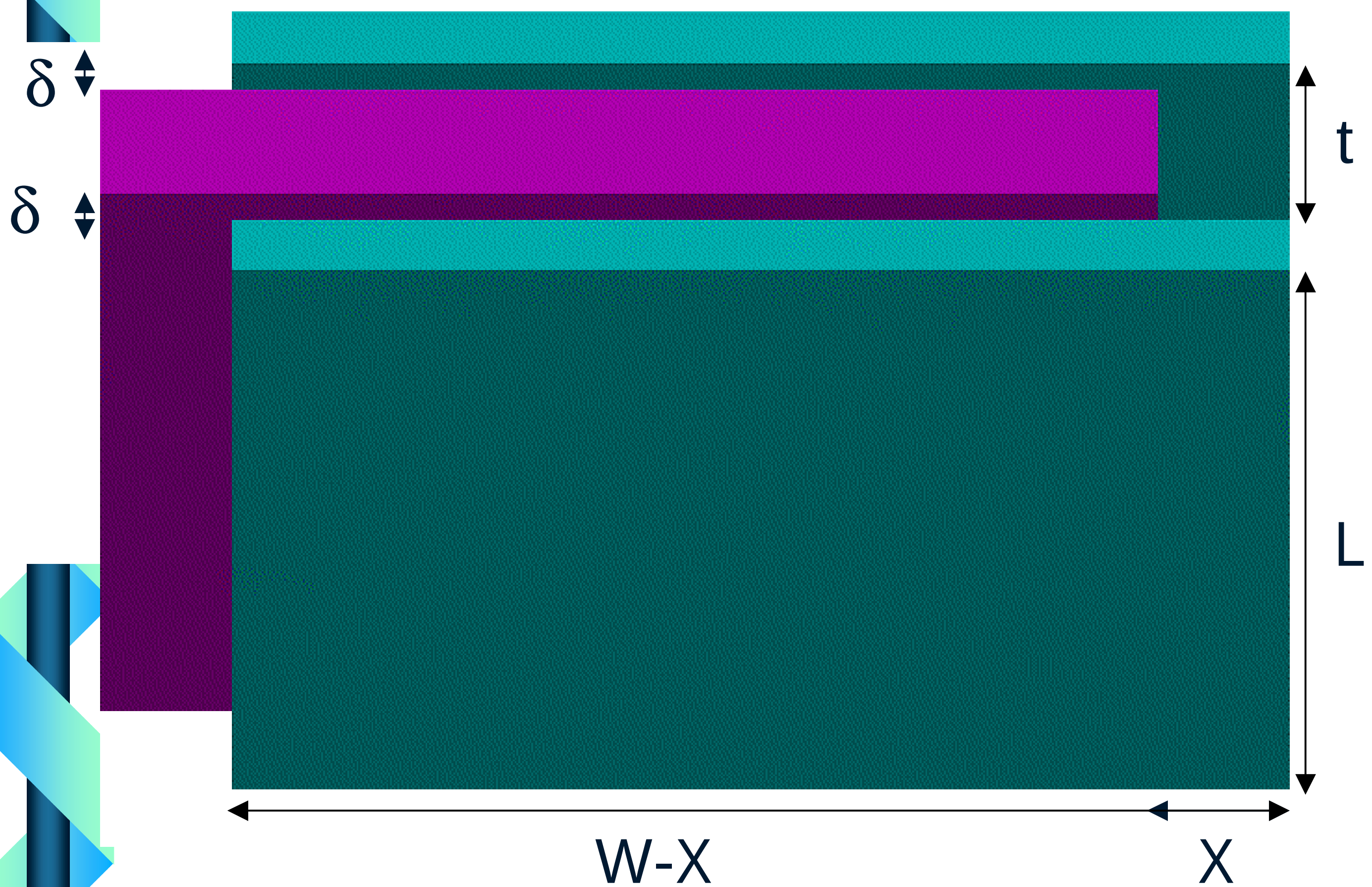
$$\tau := \frac{(.1 \cdot Volume\rho)}{G \cdot \pi \cdot L \cdot t}$$

τ(Hg)~ 71·s since P(Hg) is ~`0.13 Pa at 300K

Micro-mirror Conclusions

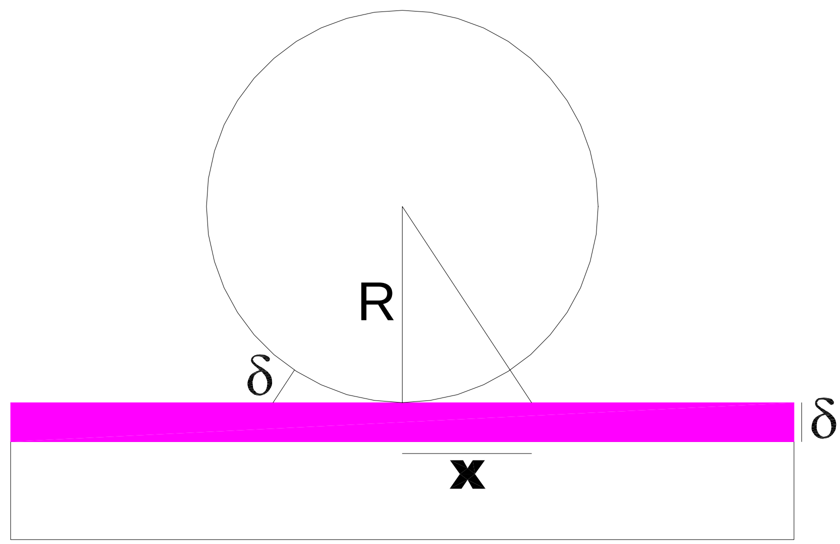
- Stress free mirror mounting.
- Actuation about two axis.
- Piston motion possible.
- Random access time of Micro-mirror ~0.7msec for 0.2mm 7μg mirror.
- Two dimensional liquid and electrostatic analysis.

Variable Capacitor



$$t \gg \delta \qquad F = -\frac{\left(\varepsilon\varepsilon_o L V^2\right)}{4\delta}$$

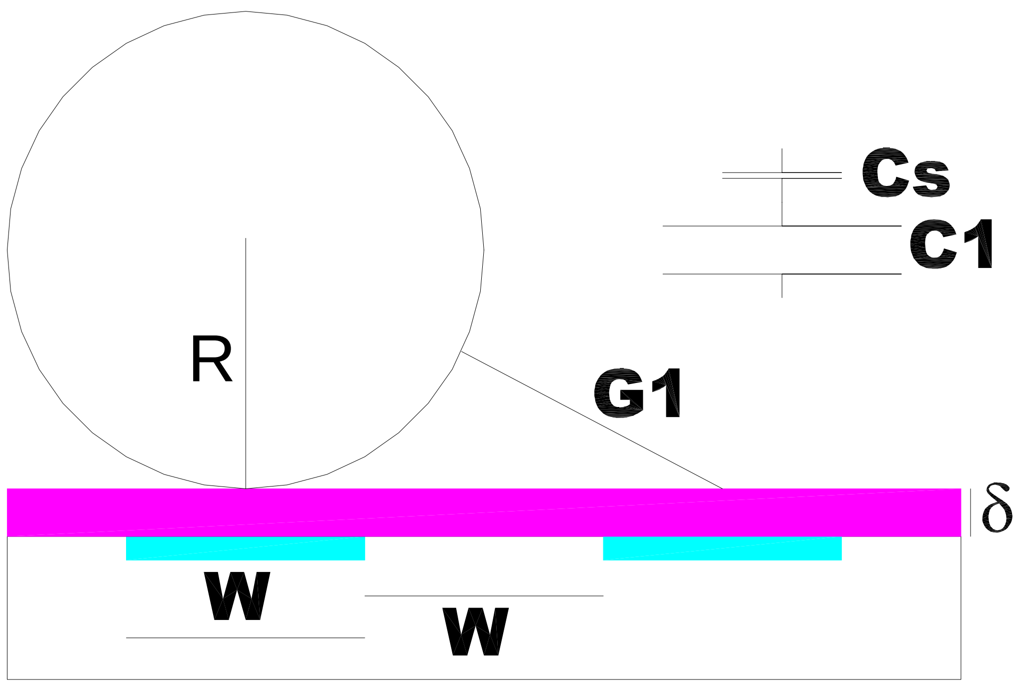
Spherical Capacitor



$$R = 500\mu\text{m}, \;\; \delta = 1\mu\text{m}$$

$$x = \sqrt{2R\delta} \;\; \text{x} \cong 30\mu\text{m}$$

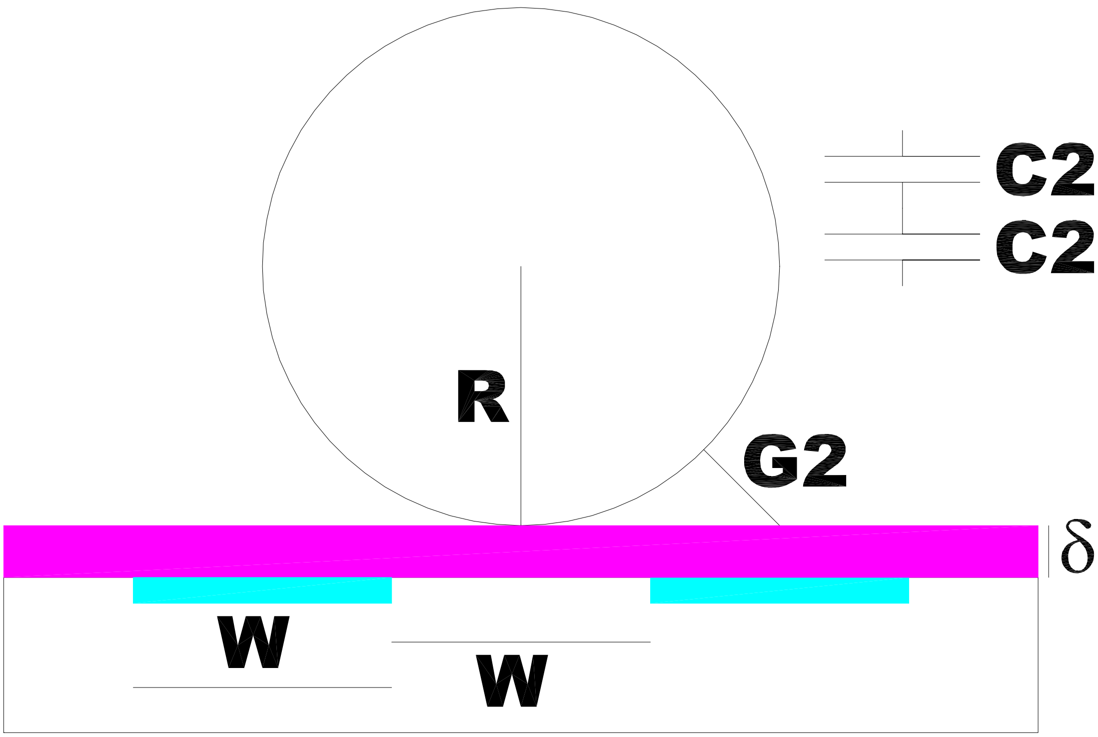
Unstable position



$$C_{T1} = \frac{1}{\dfrac{1}{Cs} + \dfrac{1}{C1}} \cong C1 = \varepsilon_o 2\pi R$$

$$W = 100\mu m, G1 = 39\mu m << R$$

Stable position

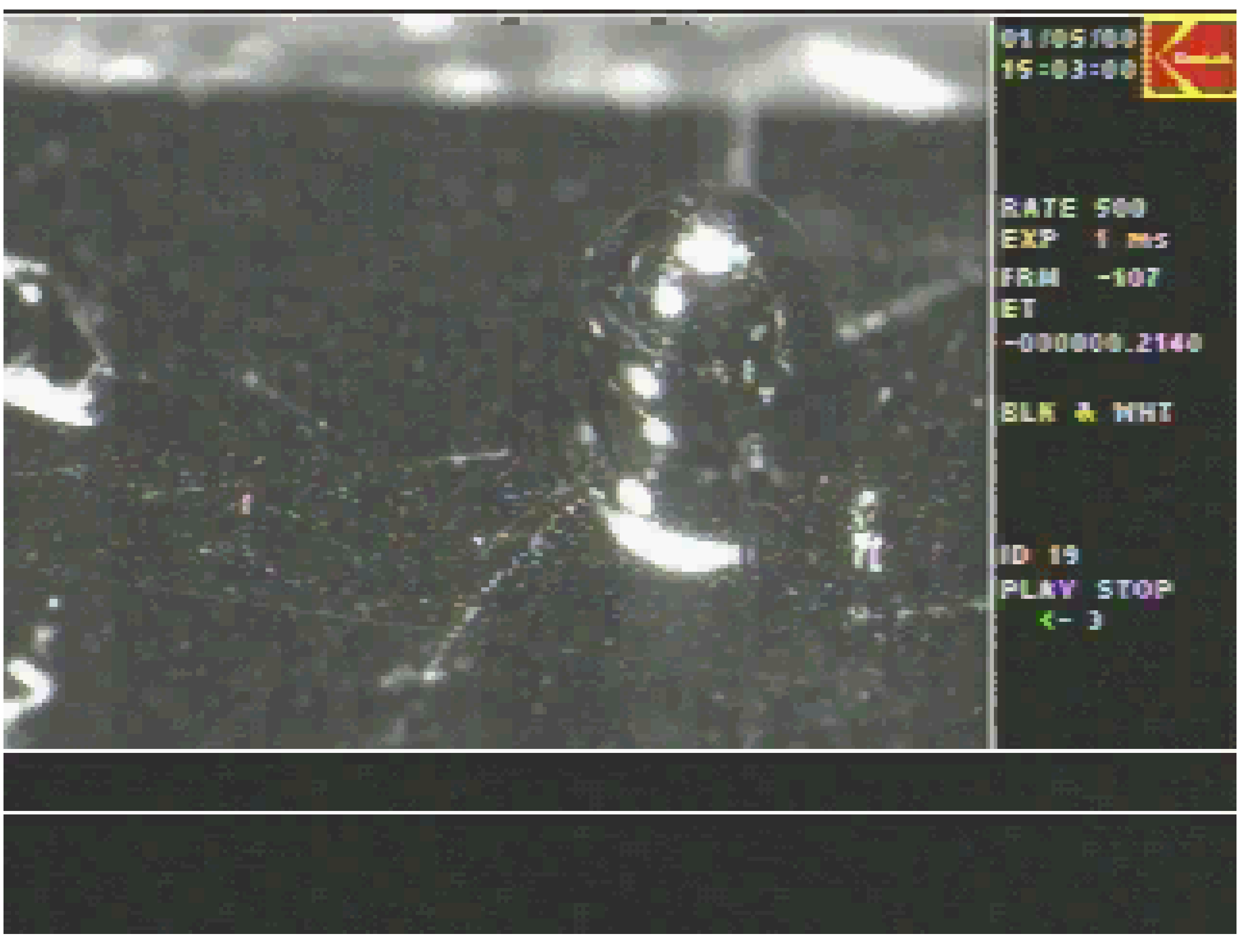


$$C_{T2} = \frac{C2}{2} = \varepsilon_o \pi R$$

$$G2 = 10\mu m << R$$

Electrostatic Force

$$F_e \approx -\frac{\Delta U}{\Delta x} \approx -\frac{C1 * V^2}{4W} = 20\mu N, V = 500V$$



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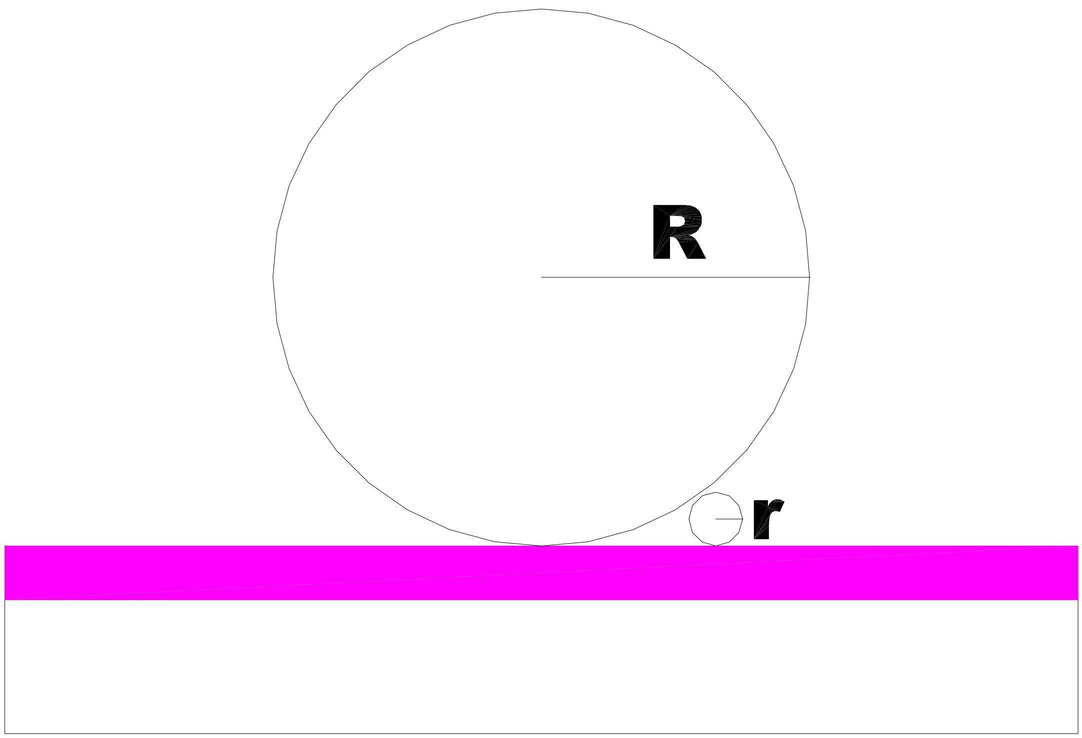
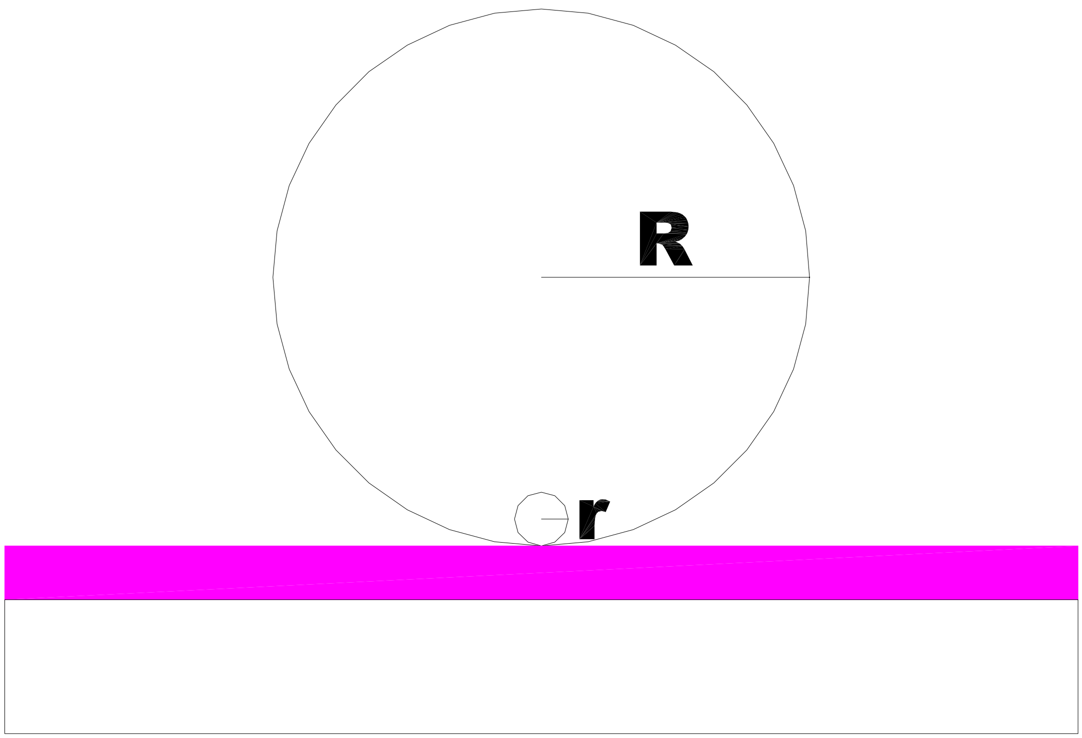
Rolling over dust



$$F_h \approx -\frac{\Delta U}{\Delta x} \approx -\frac{\rho * \frac{4}{3}\pi R^3 * g * 2 * r}{R} = 2\mu N, r = 10\mu m$$

Surface Deformation



$$F_d \approx -\frac{\Delta U}{\Delta x} \approx -\frac{\sigma 4\pi r^2}{R} = 1\mu N, \sigma = .5\frac{N}{m}$$